CSE 484 / CSE M 584: Computer Security and Privacy

Autumn 2019

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Announcements

- If you're on the class mailing list, you should have received several emails.
- Switch from Google Group to Piazza.
- Ethics form: Due next Wednesday (10/2).
- Homework #1: Due next Friday (10/4)
  - Start forming groups, feel free to use Piazza
- Lab #1: Aiming for out this week. Quiz section this week is critical!
- Office Hour changes

TOWARDS DEFENSES

Approaches to Security

- Prevention
  - Stop an attack
- Detection
  - Detect an ongoing or past attack
- Response
  - Respond to attacks

- The threat of a response may be enough to deter some attackers

Whole System is Critical

- Securing a system involves a whole-system view
  - Cryptography
  - Implementation
  - People
  - Physical security
  - Everything in between

- This is because "security is only as strong as the weakest link," and security can fail in many places
  - No reason to attack the strongest part of a system if you can walk right around it.

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Attacker's Asymmetric Advantage

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- Attacker only needs to win in one place
- Defender's response:
  - Threat Model
  - Defense in Depth

From Policy to Implementation

- After you've figured out what security means to your application, there are still challenges:
  - Requirements bugs
    - Incorrect or problematic goals
  - Design bugs
    - Poor use of cryptography
    - Poor sources of randomness
    - ...
  - Implementation bugs
    - Buffer overflow attacks
    - ...
  - Is the system **usable**?

Many Participants

- Many parties involved
  - System developers
  - Companies deploying the system
  - The end users
  - The adversaries (possibly one of the above)
- Different parties have different goals
  - System developers and companies may wish to optimize cost
  - End users may desire security, privacy, and usability
  - But the relationship between these goals is quite complex (will customers choose features or security?)

Better News

- There are a lot of defense mechanisms
  – We'll study some, but by no means all, in this course
- It's important to understand their limitations
  – "If you think cryptography will solve your problem, then you don't understand cryptography… and you don't understand your problem" -- Bruce Schneier

SOFTWARE SECURITY

Adversarial Failures

- Software bugs are bad
  - Consequences can be serious
- Even worse when an intelligent adversary wishes to exploit them!
  - Intelligent adversaries: Force bugs into "worst possible" conditions/states
  - Intelligent adversaries: Pick their targets
- Buffer overflows bugs: Big class of bugs
  - Normal conditions: Can sometimes cause systems to fail
  - Adversarial conditions: Attacker able to violate security of your system (control, obtain private information, ...)

BUFFER OVERFLOWS

A Bit of History: Morris Worm

- Worm was released in 1988 by Robert Morris
- Worm was intended to propagate slowly and harmlessly measure the size of the Internet
- Due to a coding error, it created new copies as fast as it could and overloaded infected machines
- $10-100M worth of damage

A Bit More History

- Morris: Graduate student at Cornell, son of NSA chief scientist
- Convicted under Computer Fraud and Abuse Act, sentenced to 3 years of probation and 400 hours of community service
- Now an EECS professor at MIT

Morris Worm and Buffer Overflow

- One of the worm's propagation techniques was a buffer overflow attack against a vulnerable version of `fingerd` on VAX systems
  - By sending special string to finger daemon, worm caused it to execute code creating a new worm copy

Famous Internet Worms

- Buffer overflows: very common cause of attacks
  - Still today!
- Morris worm (1988): overflow in `fingerd`
  - 6,000 machines infected
- CodeRed (2001): overflow in MS-IIS server
  - 300,000 machines infected in 14 hours
- SQL Slammer (2003): overflow in MS-SQL server
  - 75,000 machines infected in **10 minutes** (!!)
- Sasser (2005): overflow in Windows LSASS
  - Around 500,000 machines infected

… And More

- Conficker (2008-09): overflow in Windows RPC
  - Around 10 million machines infected (estimates vary)
- Stuxnet (2009-10): several zero-day overflows + same Windows RPC overflow as Conficker
  - Windows print spooler service
  - Windows LNK shortcut display
  - Windows task scheduler
- Flame (2010-12): same print spooler and LNK overflows as Stuxnet
  - Targeted cyperespionage virus
- Still ubiquitous issues, especially in embedded systems
  - E.g., our car work (OnStar, Bluetooth, CD player)

Attacks on Memory Buffers

- Buffer is a pre-defined data storage area inside computer memory (stack or heap)
- Typical situation:
  - A function takes some input that it writes into a pre-allocated buffer.
  - The developer forgets to check that the size of the input isn't larger than the size of the buffer.
  - Uh oh.
    - "Normal" bad input: crash
    - "Adversarial" bad input : take control of execution

Stack Buffers

- Suppose Web server contains this function

```
void func(char *str) {
        char buf[126];
        ...
        strcpy(buf,str);
        ...
    }
```

- No bounds checking on strcpy()
- If str is longer than 126 bytes
  - Program may crash
  - Attacker may change program behavior

Example: Changing Flags

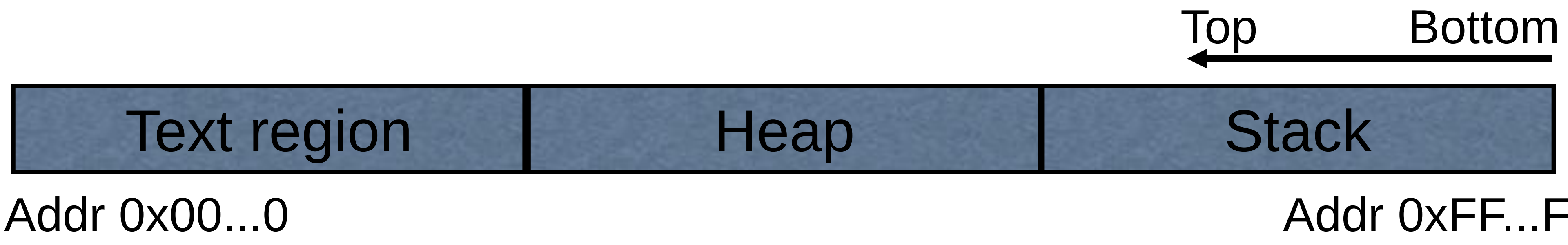
- Suppose Web server contains this function

```
void func(char *str) {
        char buf[126];
        ...
        strcpy(buf,str);
        ...
    }
```

- Authenticated variable non-zero when user has extra privileges
- Morris worm also overflowed a buffer to overwrite an authenticated flag in fingerd

Memory Layout

- Text region: Executable code of the program
- Heap: Dynamically allocated data
- Stack: Local variables, function return addresses; grows and shrinks as functions are called and return



Stack Buffers

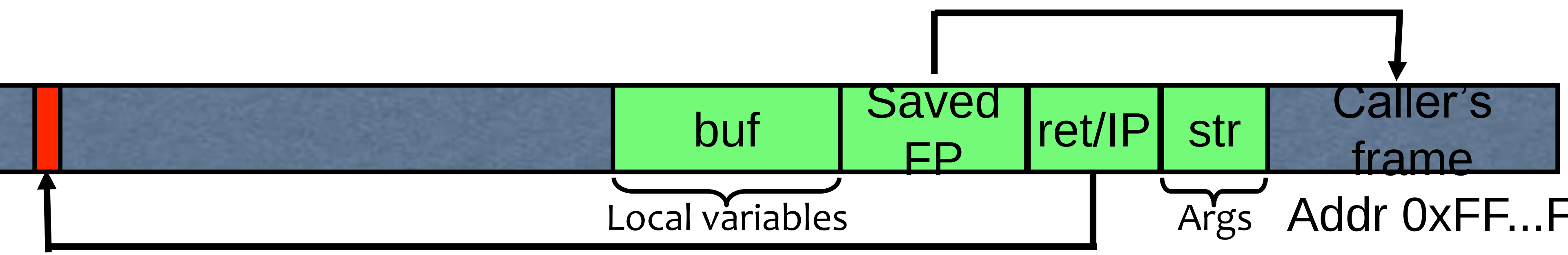
- Suppose Web server contains this function:

```
void func(char *str) {
        char buf[126];
        strcpy(buf,str);
    }
```

Allocate local buffer (126 bytes reserved on stack)

Copy argument into local buffer

- When this function is invoked, a new frame (activation record) is pushed onto the stack.



Execute code at this address after func() finishes

What if Buffer is Overstuffed?

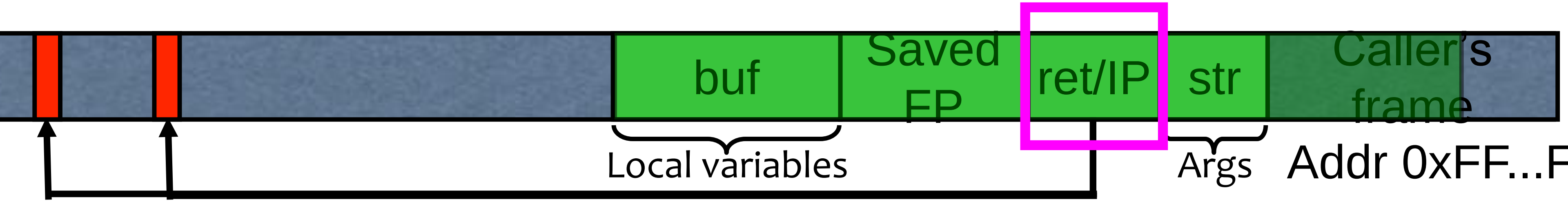
- Memory pointed to by str is copied onto stack…

```
void func(char *str) {
        char buf[126];
        strcpy(buf,str);
   }
```

strcpy does NOT check whether the string at *str contains fewer than 126 characters

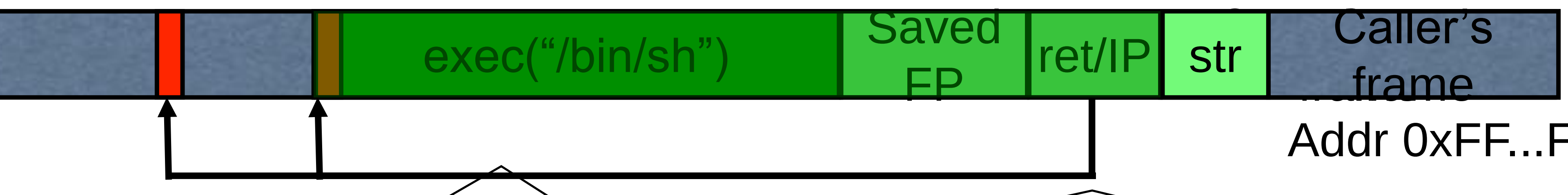
- If a string longer than 126 bytes is copied into buffer, it will overwrite adjacent stack locations.

This will be interpreted as return address!



Executing Attack Code

- Suppose buffer contains attacker-created string
  - For example, str points to a string received from the network as the URL



Attacker puts actual assembly instructions into their input string, e.g., binary code of execve("/bin/sh")

In the overflow, a pointer back into the buffer appears in the location where the system expects to find return address

- When function exits, code in the buffer will be executed, giving attacker a shell **("shellcode")**
  - Root shell if the victim program is setuid root

Buffer Overflows Can Be Tricky…

- Overflow portion of the buffer must contain correct address of attack code in the RET position
  - The value in the RET position must point to the beginning of attack assembly code in the buffer
    - Otherwise application will (probably) crash with segfault
  - **Attacker must correctly guess in which stack position their buffer will be when the function is called**

Problem: No Bounds Checking

- strcpy does <u>not</u> check input size
  - strcpy(buf, str) simply copies memory contents into buf starting from *str until “\0” is encountered, ignoring the size of area allocated to buf
- Many C library functions are unsafe
  - strcpy(char *dest, const char *src)
  - strcat(char *dest, const char *src)
  - gets(char *s)
  - scanf(const char *format, …)
  - printf(const char *format, …)

Does Bounds Checking Help?

- strncpy(char *dest, const char *src, size_t n)
  - If strncpy is used instead of strcpy, no more than n characters will be copied from *src to *dest
    - Programmer has to supply the right value of n
- Potential overflow in htpasswd.c (Apache 1.3):

```
strcpy(record,user);
strcat(record,":");
strcat(record,cpw);
```

Copies username ("user") into buffer ("record"), then appends ":" and hashed password ("cpw")

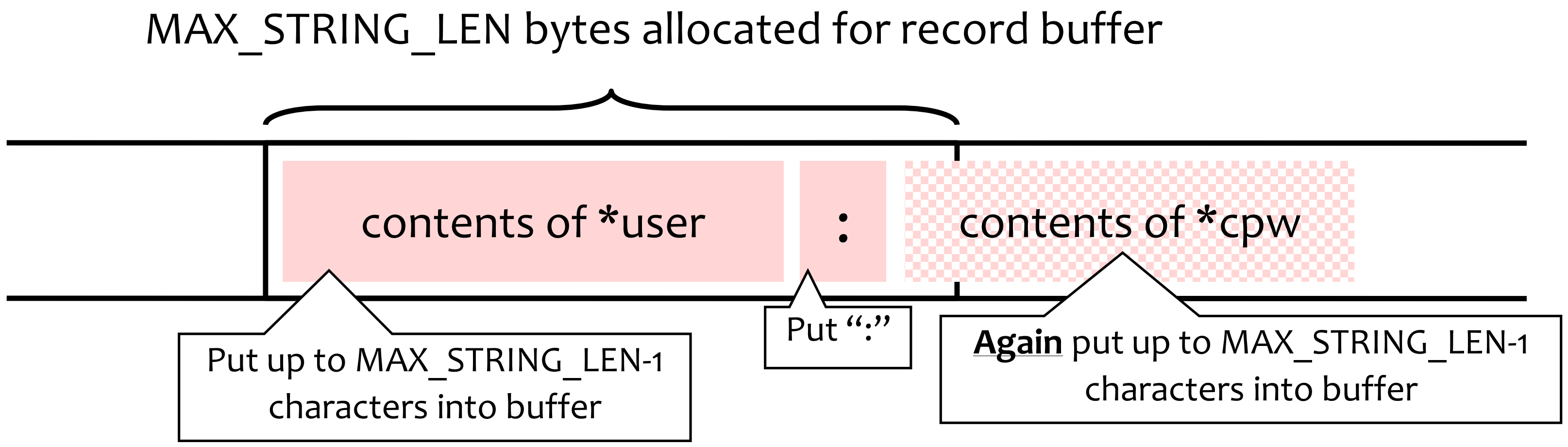
- Published fix:

```
strncpy(record,user,MAX_STRING_LEN-1);
strcat(record,":")
strncat(record,cpw,MAX_STRING_LEN-1);
```

Misuse of strncpy in htpasswd "Fix"

- Published "fix" for Apache htpasswd overflow:

```
strncpy(record,user,MAX_STRING_LEN-1);
strcat(record,":")
strncat(record,cpw,MAX_STRING_LEN-1);
```



What About This?

- Home-brewed range-checking string copy

```
void mycopy(char *input) {
     char buffer[512]; int i;

     for (i=0; i<=512; i++)
         buffer[i] = input[i];
}
void main(int argc, char *argv[]) {
     if (argc==2)
        mycopy(argv[1]);
}
```

Off-By-One Overflow

- Home-brewed range-checking string copy

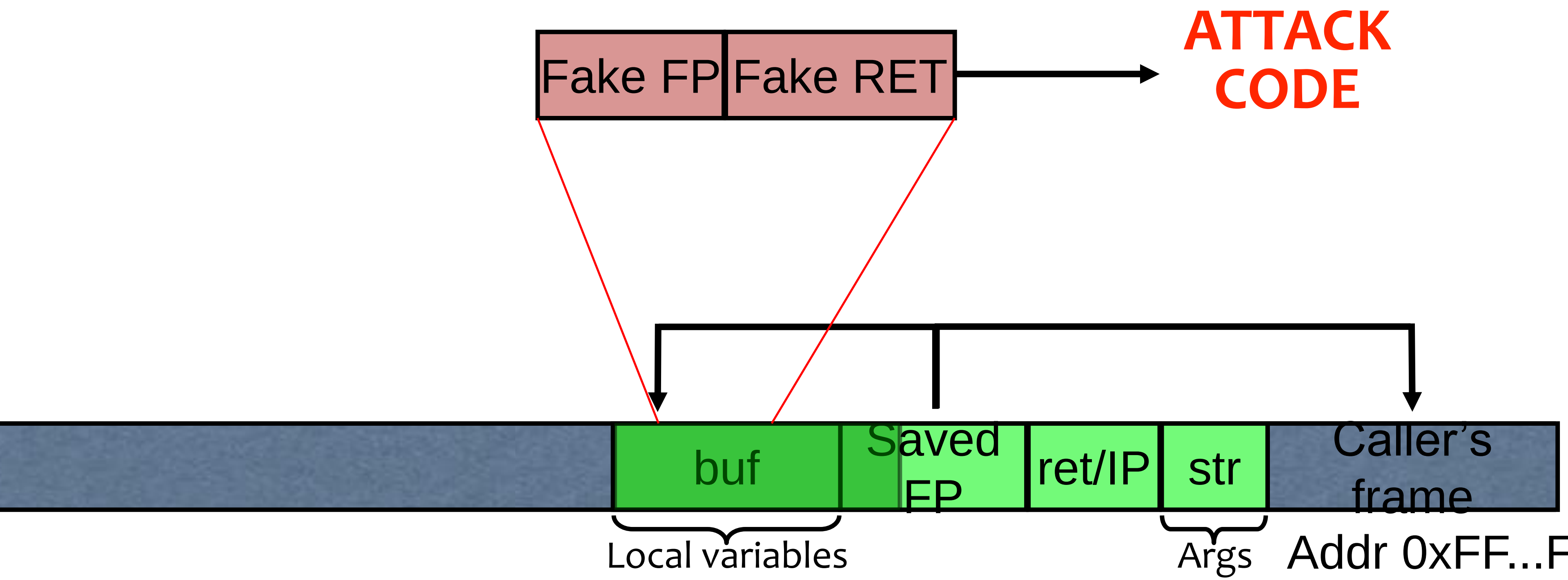
```
void mycopy(char *input) {
     char buffer[512]; int i;

     for (i=0; i<=512; i++)
          buffer[i] = input[i];
}
void main(int argc, char *argv[]) {
     if (argc==2)
          mycopy(argv[1]);
}
```

This will copy **513** characters into buffer. Oops!

- 1-byte overflow: can't change RET, but can change pointer to previous stack frame…

Frame Pointer Overflow



Other Overflow Targets

- Function pointer, format strings in C
  - More details next time
- Heap management structures used by malloc()
  - More details in section

- These are all attacks you can look forward to in Lab #1 ☺

To Do

- Ethics form (due Wed Oct 2 – do it soon!)
- Homework #1 (due Fri Oct 4)
  - Now: Groups formed? Think about events and technologies you'd like to review, ideally finish before Thursday.
- Quiz section this week critical for Lab 1
- Guest lecture on Wednesday